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SURFACE PREPARATION AND COATINGS  
DESIGN/PRODUCTION INTEGRATION  
HUMAN RESOURCE INNOVATION  
MARINE INDUSTRY STANDARDS  
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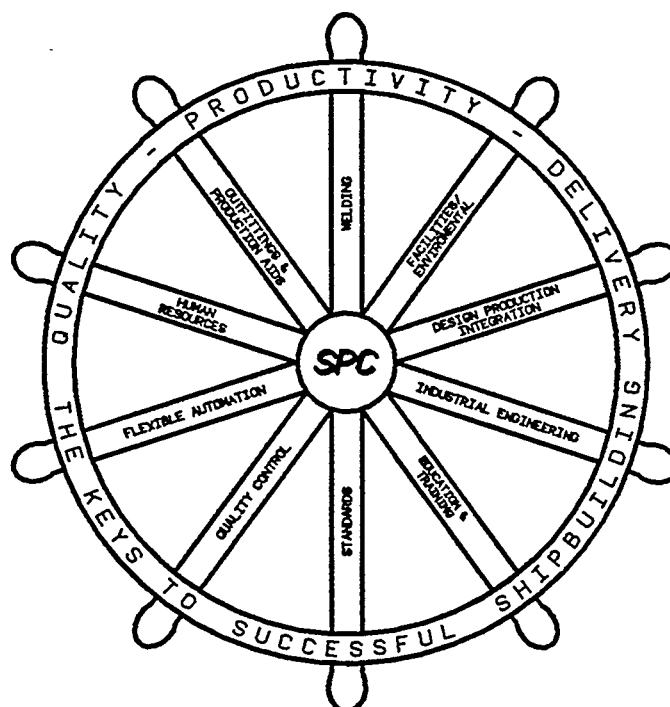
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**SHIP PRODUCTION SYMPOSIUM**



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## Design/Production Integration

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### ABSTRACT

The multiple challenges posed by ever-increasing ship sizes, technical complexity, skyrocketing material and construction costs, plus several recently introduced design requirements - such as double hulls and extensive waste treatment systems - have combined to create an increasingly involved and complicated shipbuilding environment. This paper addresses steps taken to increase design and construction effectiveness through use of a shared three dimensional (3-D) database. An improved ability to successfully compete in the highly competitive international shipbuilding market is demonstrated.

### INTRODUCTION

The United States shipbuilding industry is facing major problems from intensely competitive, and often government-subsidized shipyards in both Europe and the Far East. The outlook at this time is not promising, and the only hope of becoming competitive lies in streamlining the ship design and manufactur-

ing processes, strictly controlling production costs and overhead, and providing a top quality product that will please the customer and induce them, and hopefully others, to return to the United States with additional order in the future.

In order to survive as a viable industry, shipbuilders must not only rely on the latest technology, but also must employ every means available to simultaneously decrease cost and increase productivity. To achieve this, every task and step in the design and manufacturing process must be thoroughly evaluated to ensure maximum efficiency. Personnel who in the past have specialized within one narrow field must increase their versatility and learn to apply their particular knowledge over a broader spectrum than before.

At Ingalls Shipbuilding the concept of concurrent engineering with a comprehensive 3-D Computer Aided Design (CAD) database is applied to achieve a more streamlined and productive design for manufacturing. This method has proven capable of

eliminating many of the major and minor problems that tend to occur downstream in the material, planning, and operations stages of the ship design and manufacturing processes.

This paper provides a brief review of the subject of concurrent engineering and design/operations integration and outlines the positive aspects of implementing its principles.

#### THE PRINCIPLES OF INTEGRATING DESIGN AND PRODUCTION PERSONNEL

Until recently a ship design was created by various disciplines working separately from the start of a project; only upon completion of individual efforts were the results integrated into one cohesive design package. However, this method was inefficient and uneconomical since it invariably resulted in extensive overlaps and duplications of effort, as well as conflicts and interferences throughout the design. Accordingly, much time and cost had to be expended in backtracking and correcting already finalized series of drawings, instructions, and work packages.

Implementation of the concept of concurrent engineering has resolved many of these inefficiencies. This involves the use of integrated teams of representatives from all disciplines and crafts working in close coordination from the initial design through completion of construction. The second reason for the success of the concurrent engineering concept is the extensive use of a three-dimensional CAD system which, among many other capabilities, enables engineers, planners, and craft supervisors to

observe three-dimensional images of spaces and equipment arrangements as they actually would appear on a ship. This is a tremendous advantage over earlier methods, where the individuals involved had to rely on two-dimensional design drawings to define arrangements and installation procedures, and then mentally convert these to three-dimensions.

An additional benefit of using a CAD system is that its output can be used to create data for use in Computer Aided Manufacturing (CAM). This is accomplished through Direct Numerical Control (DNC) data - directly generated from 3-D CAD database into a computer, which then issues instructions to shop machinery for plasma arc cutting of steel and aluminum plate, pipe bending and cutting, and other fabrication functions.

Implementation of this concept has resulted in a design product with far less need for change, since all major issues and potential problems have been identified, resolved, and incorporated from the start of the design process. The overall result of this teamwork has been ship designs created with far less duplication of effort, and improved producibility, and a less expensive end product that is delivered in the shortest possible period of time.

The transition to the concurrent engineering concept and design/operation integration was initiated with an evaluation of each shipyard organization's structure, arrangement, and operating principles. For example, the engineering organization had always been divided into two distinct groups: de-

sign engineering and field engineering. Design engineering was responsible for completion of all initial design tasks and then, upon start of production, would transfer most of its responsibilities to field engineering. Although the two groups communicated well, it was evident that neither was fully capable of resolving all problems occurring during the various stages of design and production.

Accordingly, it was decided to form teams of key personnel from all departments into coherent design\operations teams for each design discipline. One group each was formed from naval architecture, marine engineering, and combat systems/electrical. Each group included a

principal engineer in charge of several other engineers, a principal designer and a number of CAD designers, senior planners, weight control specialists, material specialist, and operations supervisors.

Each team was placed under the direction of project coordinator, answerable to the director of engineering, (Fig. 1) who was responsible for scheduling, budgets, and liaison between the three design disciplines and all affected organizations.

Since engineering and design personnel could not be expected be familiar with all of the most recent manufacturing processes employed at the various craft levels, it was decided that craft supervisors should

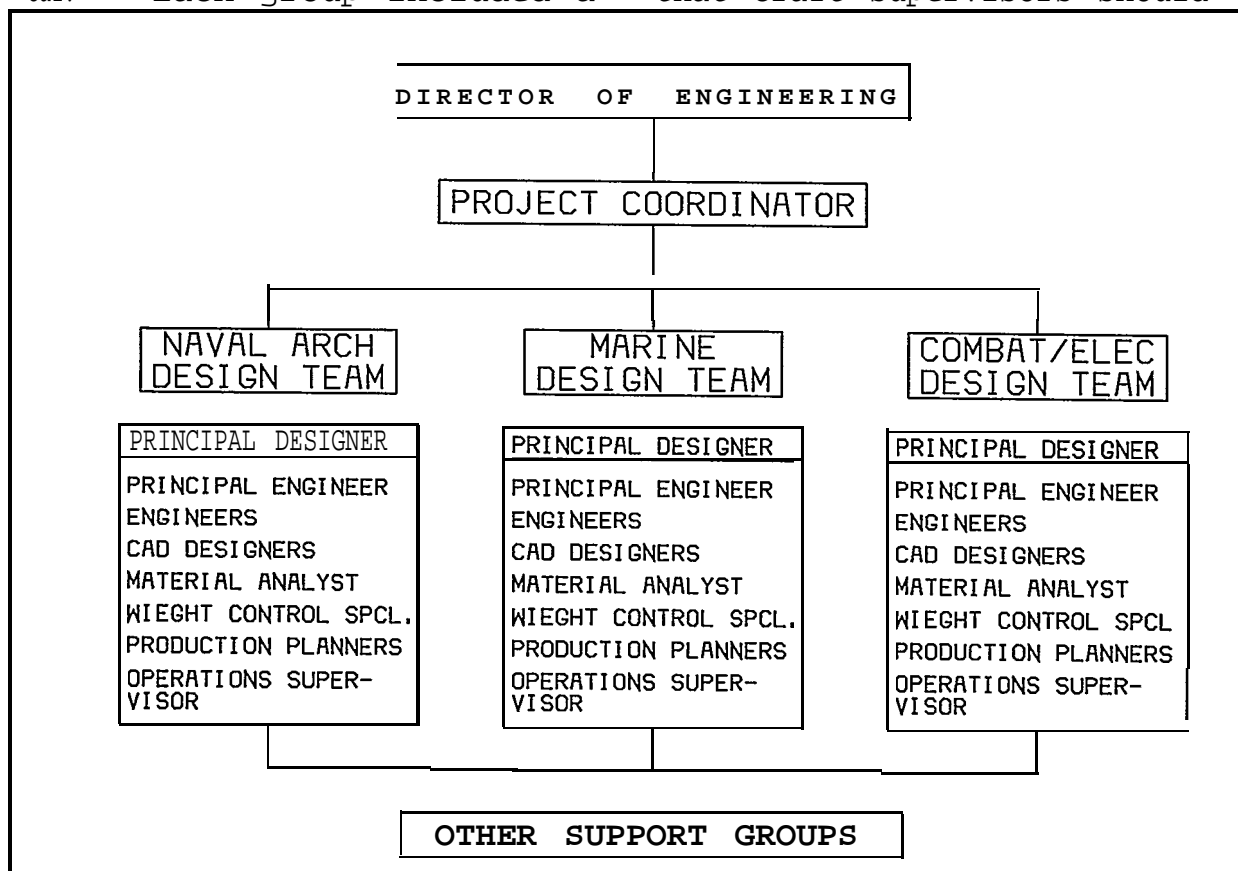


Figure I-Typical Organization Chart

be integrated into the engineering organization to provide information and to help develop a better understanding of problems that might occur at construction sites. Thus, by having experienced craft supervisors work with the design team, potential manufacturing problems could be corrected prior to release of drawings and start of construction. This saved much valuable time that might otherwise have to be wasted in taking out erroneously installed equipment or systems.

Subsequently, it was found that one of the main benefits of integrating operations personnel with the design team was the valuable practical information these experienced supervisors were able to pass to the designers. They inspected congested areas on the ship to determine the best possible means of production.

By using the Project Review Terminal (PRT) they could visualize all components, and make valuable suggestions to the design team for enhancement of the basic design. Operations personnel also assisted in the selection of candidates for machinery packages, selected HVAC and pipe spools for fabrication, and identified assembly beaks in spools for distributive systems.

By following the design from its inception, the craft supervisors became thoroughly familiar with all spaces, and after a year or more of constant observation of the design, they were able to provide expert guidance and assistance to crafts personnel on any problem anywhere in the ship. This greatly increased production

efficiency and, in general, resulted in an improved product which could proudly meet the production motto of "HEAD OF SCHEDULE AND UNDER BUDGET!"

#### DESIGN TEAM RESPONSIBILITIES

With these teams of highly qualified personnel in place the shipyard was ready to accept the challenge of constructing the first totally CAD-designed and CAM-produced ship using concurrent engineering principles. The following are brief descriptions of the responsibilities placed on the individual team members.

##### Principal Engineer

The principal engineers were responsible for ship systems and technical areas, and supervised a group of other engineers who performed analyses and developed systems within each of the technical areas. They also functioned as the primary customer contacts in regards to technical matters.

In addition, the principal engineers monitored each design task, held design reviews to resolve conflicts, and interfaced with all disciplines. Not only did they act as experts within their own field of endeavor, but they were required to familiarize themselves with the overall design to a degree where they were able to provide objective and positive input to areas not normally under their cognizance.

##### Engineer

Under the general guidance and leadership of the principal engineers, and based on the ship's specifications and system



design requirements, the team engineer developed one-line diagrammatic drawings (diagrams), to include the latest vendor information, stress analyses, and systems calculations. Next, the information was compiled and loaded into the CAD database under the guidance of the engineer, and they regularly updated to ensure that each designer would have the most recent information available for the design effort.

Other responsibilities included interfacing with vendors regarding major equipment, preparations of advance bills of material for long lead items to support production schedules, participation in the resolution of design problems, and acting as a source of on-site information for the CAD designer.

#### Principal Designer

Each designer organization appointed one lead designer to coordinate the initial design for their respective discipline. The principal designers from all disciplines were co-located in the CAD area, and began the initial design using all available information to generate one-line composite drawings for loading into the CAD database.

The fact that personnel from all organizations were located within the same room or area provided the vital communications link required to incorporate all valid information into the design.

Whereas the principal engineers were responsible for ship systems and technical areas, the principal designers controlled development of the design within each design zone. They inter-

faced on a continuing basis with the principal engineers, CAD designers, material analysts, weight control specialists, operations personnel, and production planning personnel to ensure that valid comments from all sources were incorporated into the design. In addition, they chaired design reviews for their respective discipline, or for the design zone under their responsibility.

The principal designer worked directly with the assigned operations\craft personnel from the start of the project. Each component was scrutinized, placed on the composite, and loaded into the CAD database to support fabrication and installation. Various components were grouped to support machinery packaging. These areas of the machinery spaces were designed for fabrication in the machinery package shop, and subsequent landing on the ship. With the assistance of production personnel, these packages were structurally designed to support equipment, distributive systems, outfitting, and testing.

Following completion of the design, the principal designers moved their work stations to the production area where they coordinated with operations personnel and field engineers to resolve production conflicts. Due to their extensive knowledge of the overall project they were usually able to solve production problems with minimum delays or disruption to other work in progress.

#### CAD Designer

The CAD designer would load the 3-D CAD database using diagrams, one-line composite

ketches, contract guidance drawings, and preliminary structural disciplines to develop arrangements and distributive systems. After completion of the zone structural models, major equipment was created and arranged. These included maintenance envelopes for access control, equipment removal, shock and vibration, and headroom. A priority routing system was then used to design HVAC, wireways, and large piping systems. The last items to be generated were smaller pieces of electronic equipment, local wireways, outfitting, furnishings, and small pipe.

The CAD designer interfaced with all affected organizations and personnel during this process. The design of distributive systems was monitored on a continuing basis by the principal engineer, principal designer, and personnel from material, operations, and planning. This was the phase of the design in which all responsible parties would correct potential problems that might occur downstream.

Using a CAD database provided the opportunity to interference check all systems and components as they were placed in the CAD model. All observed problems were logged and tracked by the CAD designer, and models were not released for drawing extraction until all interferences had been cleared.

Following completion of the design, the CAD operator was responsible for extracting the design drawings from the database. Such extractions were created to support the needs of the planners and craftsmen. In lieu of conventional types of

drawings, many of the distributive systems drawings were created to support downhand welding. Operations and planning personnel defined which areas were to be developed using this method; this was a valuable asset to operations personnel, as it provided a clear perspective of components being installed.

Upon start of construction, lead CAD designers were relocated to the production area, along with their CAD work station, to coordinate with and support operations personnel with on-site resolution of production problems. This eliminated the functions normally performed by field engineers, since the operator identified the problems on the ship, corrected the CAD database, updated the DNC, and revised the applicable drawing. Being able to work on site with operations personnel who were familiar with the CAD design tools greatly expedited processing of each change.

#### Material Analyst

The materials entered into the CAD database were controlled and monitored by the material analyst, who decided what would actually be procured for the construction project.

All materials were programmatically sourced by the material analyst from each CAD model, and checked to verify that all components were identified for purchasing. Checks were also made to identify non-standard items with long lead times.

Suggestions would occasionally be made by the analyst to the principal engineer to substitute one material for

another, either due to a large in-yard inventory, or to save in cost.

#### Weight Control Specialist

Since all ships have stringent weight restrictions, it was the responsibility of the weight control specialist to monitor all components placed in the CAD models. As the design was being generated, preliminary bills of material were extracted for the purpose of evaluating the weights of the materials used. If lighter-weight substitutions could be found for components, and still met the required specifications, then the weight control specialist requested the design team to make the substitution.

Also, in order to maintain a load balance of the components placed on the ship, it was the weight control specialist's responsibility to calculate all loads and establish centers of gravity. If it was necessary to relocate components, specialist would identify these to the team for relocation action.

#### Production Planning and Billing Personnel

These specialists, normally located in the production area, were relocated with CAD designers to plan and stage the fabrication and installation of each component. The information entered into the CAD design models included all applicable location, planning, and billing data. As the design was firmed up in a particular zone or area of the ship, the models were moved to the planners. Production planners, in conjunction with operations personnel, evaluated each component in each

model. Pipe and HVAC spools were identified at that time, and items assigned to specific bills to be fabricated, installed in the pre-outfit stage, and subsequently in the final outfitting stage.

#### Operations Supervisor

It was the operations supervisor's responsibility to monitor the entire design process as the representative of manufacturing. They would provide input in any area to increase the productivity, select candidates for machinery packaging, select HVAC and pipe spools for fabrication, and identify assembly breaks in spools for distributive systems. Because they were able to see the design as it progressed, the operations supervisors became very familiar with each space. After a year of reviewing the plans they knew exactly what their job was and how to do it.

#### DESIGN DEVELOPMENT PROCESS

The detail design effort was divided into three phases: functional design, transition design and working instructions. (Table I).

The functional design involved preparation of basic engineering calculations, equipment selection, and preparation of schematic diagrams for pipe, vent, and electrical systems. Items such as longitudinal strength, superstructure air blast resistance, and other basic structural analyses were also completed in this phase. In addition, key space arrangements were established, and weight budgets allocated to various systems and equipments.

STAGE 1	STAGE 2	STAGE 3
FUNCTIONAL DESIGN	TRANSITION DESIGN	WORKING INSTRUCTIONS
SPECIFICATIONS REVIEW SCANTLING CALCULATIONS & PREPERATIONS LINE FARING C & A DEVELOPMENT KEY SPACE ARRANGEMENT SYSTEM CALCULATIONS WIEGHT REVIEWS PRELIMINARY DISTRIBUTIVE SYSTEM ROUTING WELDING PLANS STANDARD DETAIL DEVELOPMENT MACHINERY PACKAGE SELECTION ADVANCE BILL OF MATERIALS DEFINE ASSEMBLY BREAKDOWNS CREATE INTERFERENCE CHECKING PROJECTS	FINAL MAIN STRUCTURE MODELS DEVELOP CONNECTING STRUCTURE & FOUNDATIONS DEVELOP FINAL EQPT. ARRANGEMENTS DELVLOP DISTRIBUTIVE SYSTEM ROUTINGS FINALIZE MACHINERY PACKAGES PENETRATIONS LOAD DNC DATA LOAD PLANNING & BILLING DATA DEFINE FABRACATION REQUIRMENTS DEFINE INSTALLATION REQUIRMENTS FINAL INTERFERENCE CHECKING FINALIZE BILL OF MATERIALS INCORPORATE ALL OUTSTANDING COMMENTS	DEVELOP STRUCTURAL FABRICATION DRAWINGS DEVELOP STRUCTURAL INSTALLATION DRAWINGS DEVELOP FINAL ARRGT. DRAWINGS DEVELOP FINAL MACHINERY PACKAGES GENERATE DNC DATA DEVELOP FINAL SHOP FABRICATION SKETCHES DEVELOP INSTALLATION DRAWINGS

**Table I -Zone Breakdown Table**

The zone design phase involved creation of a three-dimensional CAD product model for each design zone. The product model showed all elements of the ship: including structure, equipment arrangements, piping and ventilation systems and hangers, wireways, waveguides, and foundations. The product model was checked for interferences and compliance with all specifications prior to start of the production design phase.

The production design phase involved determining of the design geometry. The purpose was to prepare a design that would be in the most usable format possible for the craftsmen. Work packages for shop fabrication and field installation were also prepared in this phase. Material allocation was an important part of this phase. Raw material was allocated to shops with fabrication packages, and completed shop sub-assem-

blies allocated to pre-outfitting and outfitting packages.

During the above phases, information was programmatically associated to each component in the CAD models by planners experienced in operation of the CAD system. This knowledge gave planning and operations personnel a valuable insight into the actual design, which permitted them to communicate and interface far more effectively with engineers and CAD designers than under the conventional methods used in earlier projects.

#### PROJECT REVIEW

As the results of, the design effort began to materialize, a Project Review Terminal (PRT) was put into use. This terminal was a work station capable of providing true 3-D perspectives of each design zone (Fig. 2) as it was generated in the CAD database. The colored

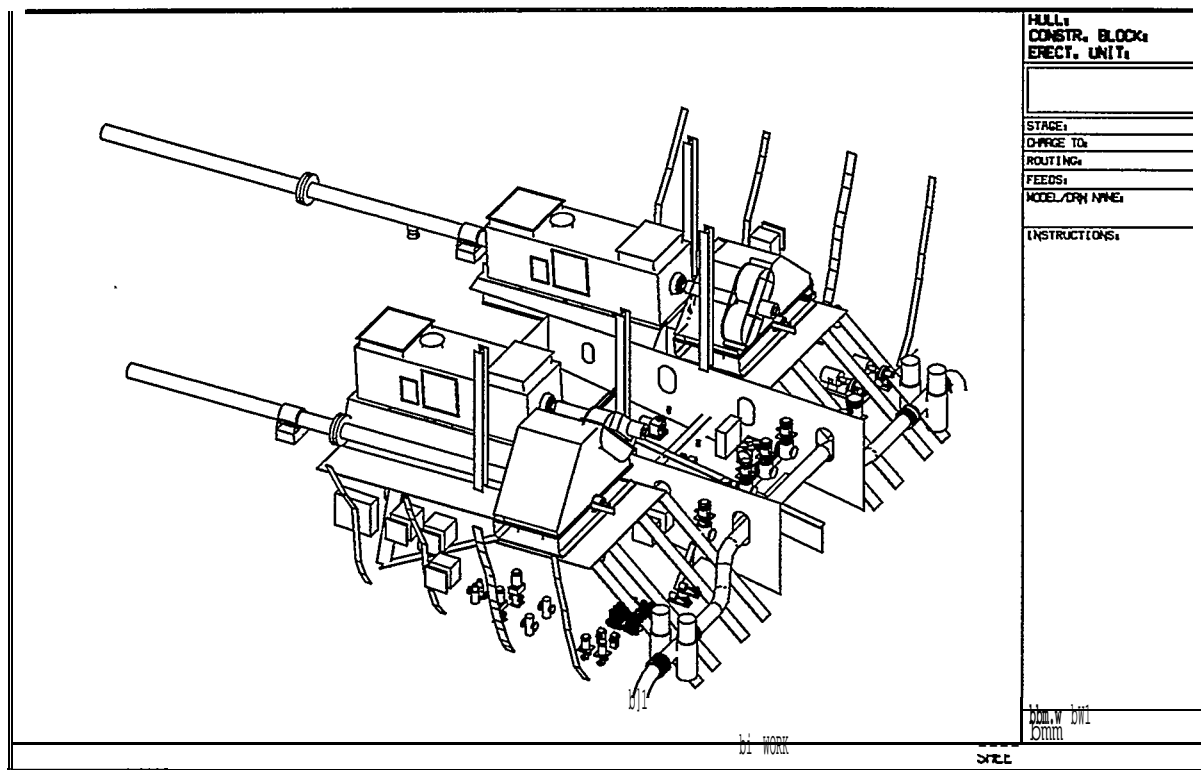


Figure 2 - Typical PRT Image

and shaded images, which may be available up to two years prior to construction, showed the model as it would appear to the craftsman working on the ship. Also, it might be viewed from any angle, and could be inverted from its design orientation to show how it would appear during various stages of construction. A built-in "blanking feature" allowed different systems or items of equipment within a compartment or space to be either shown or blanked out at will.

One of the benefits of the PRT was that, for example, the supervisor in charge of piping systems in a machinery space would know exactly how the space would look and be equipped prior to installation of the first piece of pipe. Also, in view of a supervisor's experience with earlier construction projects, they might, based on the PRT presentation, be able to identify potential installation prob-

lems or conflicts and arrange to have these corrected prior to start of construction. They might also be able to assist planning personnel with start of construction, and with information regarding which portions of each system should be installed during what phase. These "lock-out areas" - as they are called - could be clearly defined on the PRT, and appropriate action could be taken to avoid expensive and time-consuming rip-out of components installed in the wrong sequence.

At this stage, occasional minor items that might have been overlooked by the designers in the initial phases were identified by operations and planning personnel. These people acted as "checks and balances" throughout the design phase, thereby contributing to the creation of a superior product, with resulting improvements in production, time and cost.

As the design was finalized, all applicable drawings were extracted by the production planners and plotted for distribution to the crafts.

#### CAD/CAM INTERACTION

An additional timesaving benefit of using the CAD/CAM system was that the CAD equipment was capable of producing magnetic tapes containing machine instructions which would direct the operation of shop manufacturing machinery. This was accomplished through the use of Direct Numerical Control (DNC) data, which was generated by downloading numerical data into a computer as a manufacturing aid for pipe bending, plasma arc cutting of steel and aluminum, and other functions. This process was normally performed subsequent to completion of the design process; however, with the integrated CAD database offsets would directly download!

For example, instructions regarding where to create a break in a pipe or HVAC spool were fed into the CAD database by operations and planning personnel as part of the design. This information, in turn, fed a computer program which analyzed each spool and its contents and automatically generated DNC data, which then was downloaded to operate the shop machinery bending or cutting the pipe. These instructions were direct extracts from the CAD models. There was no human intervention and, thus, if the model was correct, the DNC data would be correct, and increased productivity was achieved.

#### ADVANTAGES AND BENEFITS OF CAD/CAM

Some of the notable benefits derived from use of the CAD\CAM system in conjunction with the concurrent engineering concept were as follows.

##### Improved Design Team Access

Design data entered in the CAD system could readily be called up on the terminals for review by team members. Manual designs, on the other hand, tend to remain hidden in the numerous partially completed drawings and sketches that are in evidence during the design phase.

##### Increased Productivity

Much redundant work was eliminated by relying on model libraries for such items as background arrangements, standard details, and equipment models.

##### Development of Production Work Packages

As soon as a CAD model was developed and interference checked, it could be used for extraction of construction drawings. Such work packages contained only the information and material needed to support a particular work operation. (Fig. 3). This freed craftsman from having to extract the required work information from large system-oriented drawings. Separate packages were prepared for assembly pre-outfitting, shop fabrication, and final outfit work.

BRAZE/MAILED JOINT TABLE	
PRESSURE	150 PSIG
MATERIAL	30-10 CMA
TEMPERATURE	86° F
CLASSIFICATION	P-2, P-3B
FLUID	SEAWATER
WELD PROCEDURE	WE-1
CLEAN	NA
PAINT CODE	NA
STRESS RELIEVE	NA
ANNEALING	NA
NORMALIZATION	NA
TEMPERING	NA
N.D.T.	VISUAL HYDRO
BOND DIAMETER	50 & 30
TEST REQUIRED	HYDRO, 200 PSIG
PROTECTION	GRADE 3
SILVER BRAZE	WE-18
WELD JOINT DESIGN NUMBER	
SLIP ON COUPLING	NA
SOCKET WELD FITTING	NA
SOCKET WELD FLANGE	P-15
SLIP-ON FLANGE	NA
STRUCTURAL SUEYIC	P-17
BRANCH CONNECTION	P-63
WELDING OUTLET	P-67
BOSS OF PIPE	P-70
EXPANDED PIPE JOINT	NA
BUTT JOINT FIELD	P-2
BUTT JOINT SHOP	P-2
BUTTERFLY FLANGE	P-15

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valuable practical information these experienced production supervisors were able to convey to the designers. This eliminated many potential problems during the production stage.

Craft supervisors working with the design team from its inception became thoroughly familiar with the design, and therefore were able to provide expert guidance to craft personnel on any problem anywhere in the ship. This resulted in increased production efficiency.

Application of the concept of concurrent engineering has proven to be a valuable asset. Some shipyards may find, in conjunction with the method and

by experimentation, that a mix of conventional and computerized methods are more effective in their particular endeavors than strictly one or the other.

The overall conclusion is that application of the design/operation integration concept can drastically reduce the number of problems normally encountered during the ship construction. As a result, production will increase and the goal of "AHEAD OF SCHEDULE AND UNDER BUDGET" will be achieved. The design/operation integration concept is a valuable and positive approach to the continued survival of the United States shipbuilding industry.



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